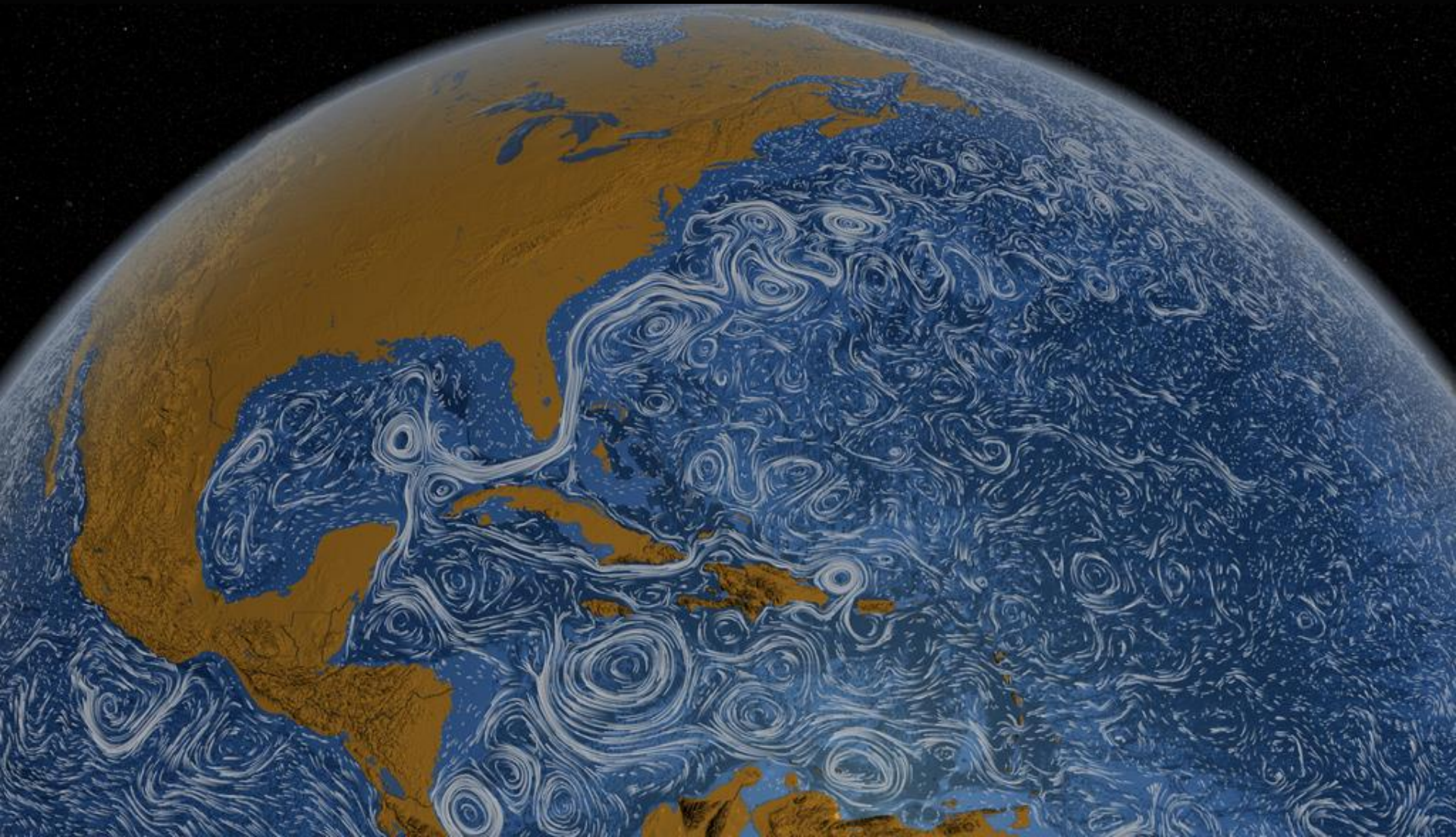


# OCEAN CIRCULATION



# Processes at the Ocean Surface:

1. Water heating by the Sun, ↑ **temperature**
2. Water evaporation (salt is left behind), ↑ **salinity**
3. Precipitation (fresh water input), ↓ **salinity**
4. Water cooling (cold winds/ice masses), ↓ **temperature**
5. Ice melt (fresh water is released), ↓ **salinity**
6. Ice formation (salt is left behind), ↑ **salinity**
7. Large river inflow (fresh water is released), ↓ **salinity**
8. Water movement (pushed by winds/tides)

# Processes in the Deep:

9. Water rise and fall (density difference)
10. Deep water flow downhill at the ocean bottom

Interplay of these processes defines **ocean circulation**.

# Ocean Circulation

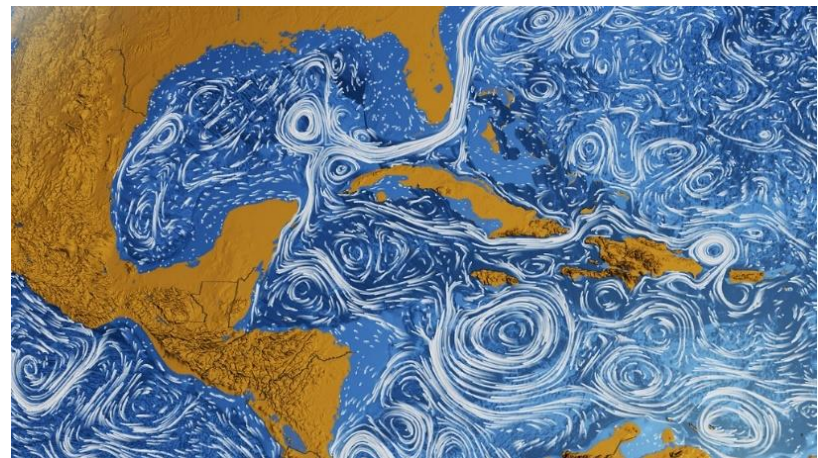
Water in the ocean is in constant motion.

- An **ocean current** is the movement of seawater in a certain direction (like a river in the ocean):
  - surface currents
  - deep currents
  - vertical currents
- Ocean **circulation** is the **combined effect of all currents** that move in oceans.

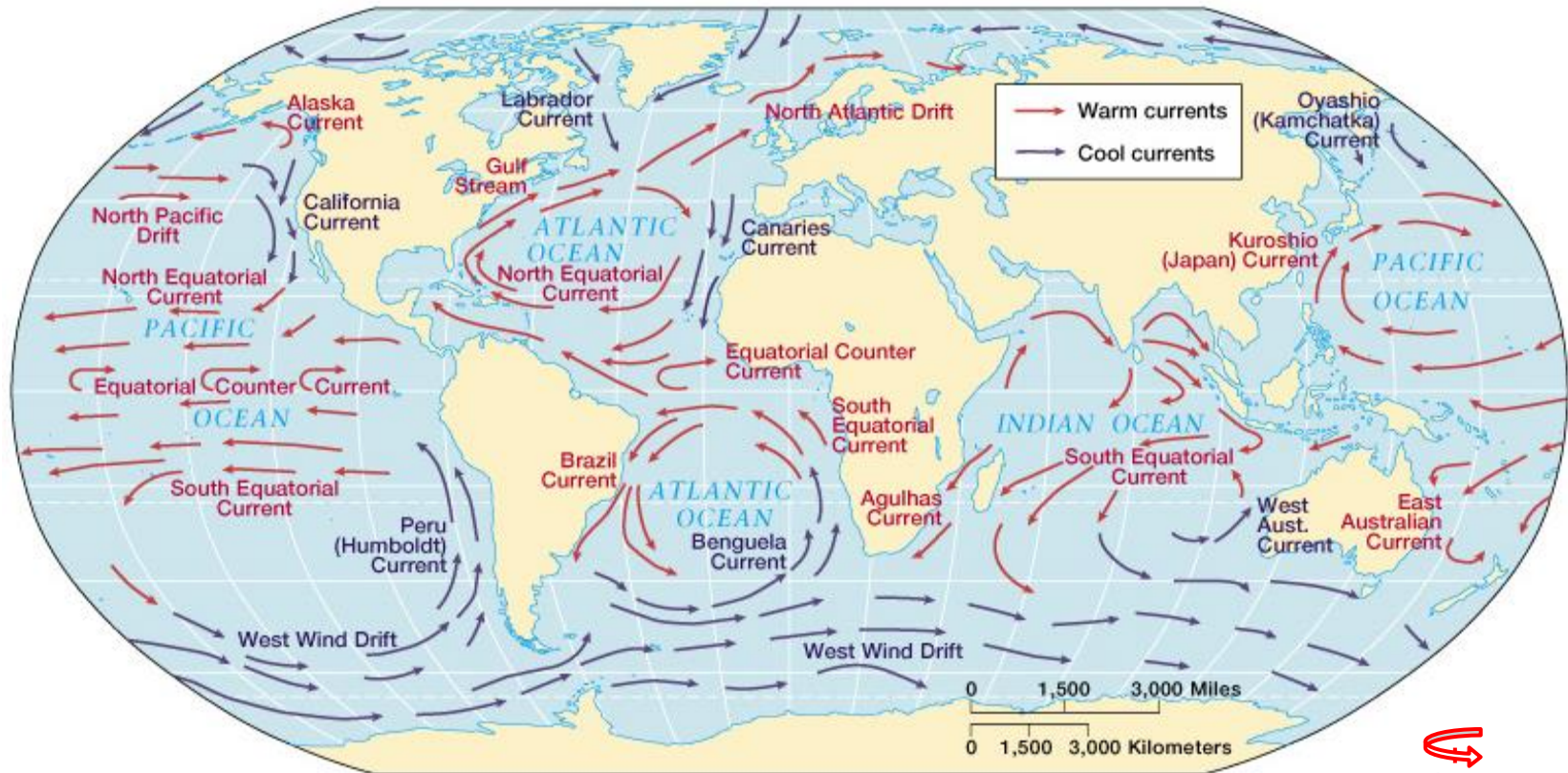
NASA Perpetual Ocean

<https://www.youtube.com/watch?v=xusdWPuWAoU>

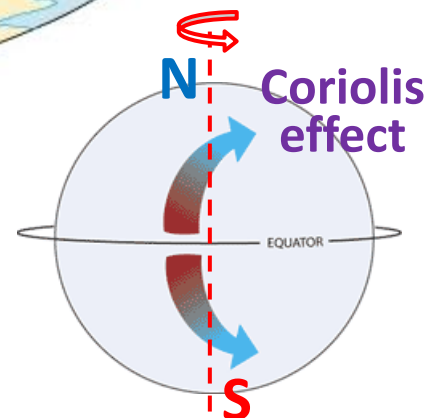
Visualization of global ocean  
*surface* currents 2005-2007



# Surface Currents are wind driven

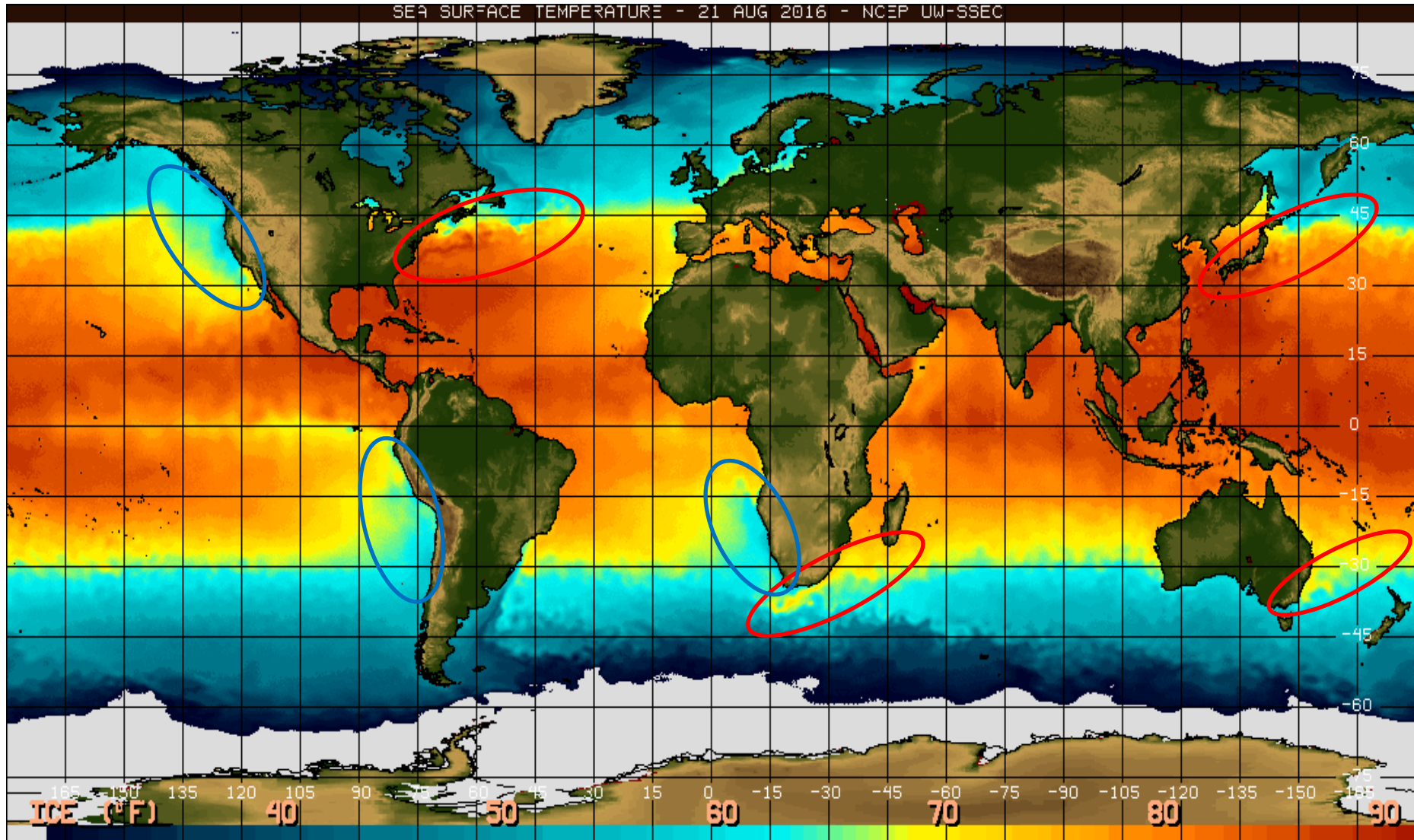


- Caused by friction between water and moving air.
- Horizontal, push the **top 400 m layer of water**.
- Form large circular patterns called **gyres** due to **Coriolis effect** (clockwise in Northern Hemisphere counterclockwise in Southern Hemisphere)



# Ocean Currents Symmetry

is evident from the ocean surface temperature map



# Gulf Stream



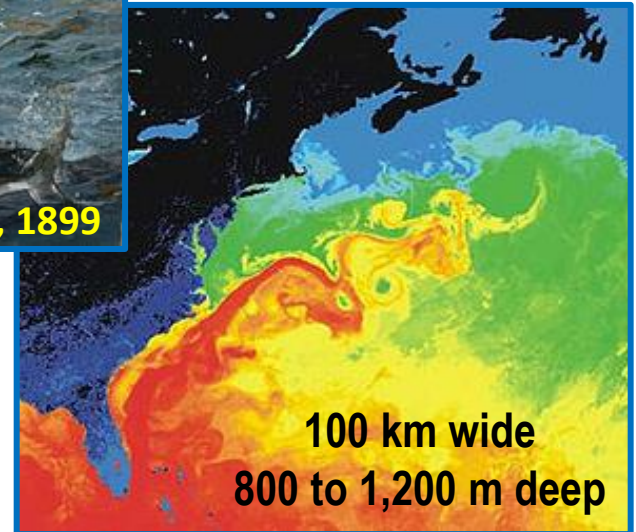
The **Gulf Stream** is a **strong, fast moving, warm** ocean current that originates in the Gulf of Mexico and flows into the Atlantic Ocean at a speed of about 1-5 mph. It transports nearly **4 billion cubic feet of water per second**, an amount greater than that carried by all of the world's rivers combined.



**The Gulf Stream, Winslow Homer, 1899**

- First discovered in **1513** by the Spanish explorer **Juan Ponce de Leon** and was then used extensively by Spanish ships as they travelled from the Caribbean to Spain.

- In **1786**, **Benjamin Franklin** mapped the current, further increasing its usage.

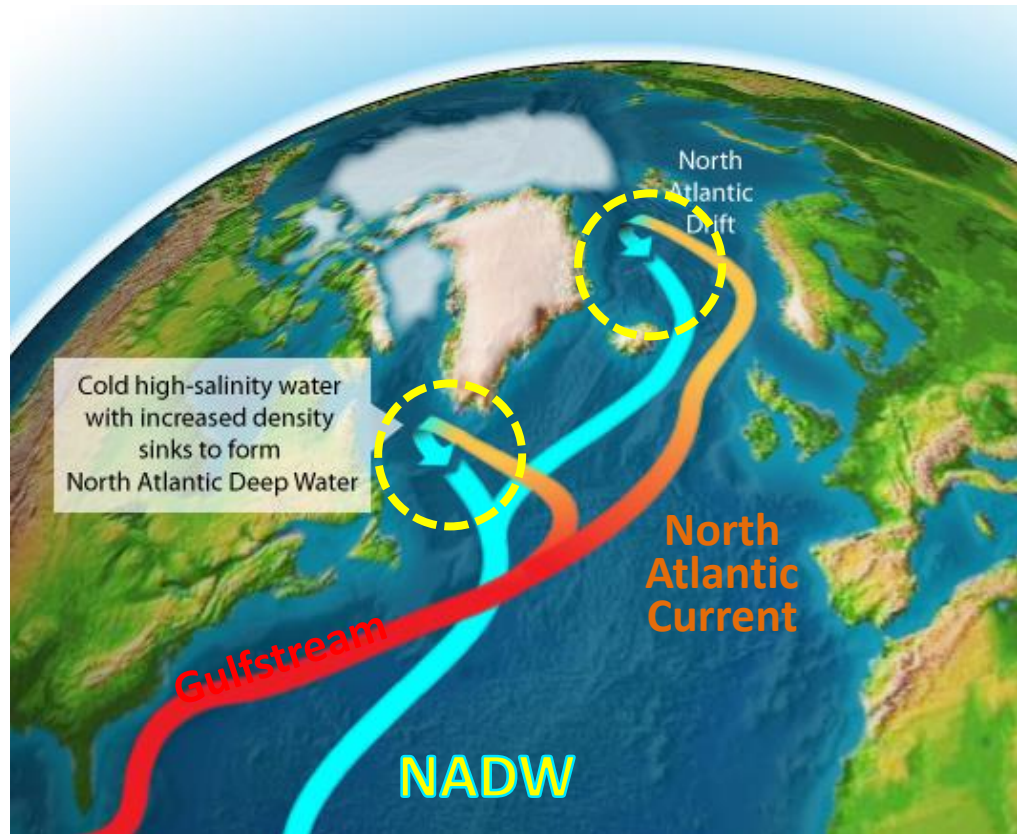


100 km wide  
800 to 1,200 m deep

# Deep Currents

**Deep currents** are directed by ocean bottom relief: water masses move “down the hill”.

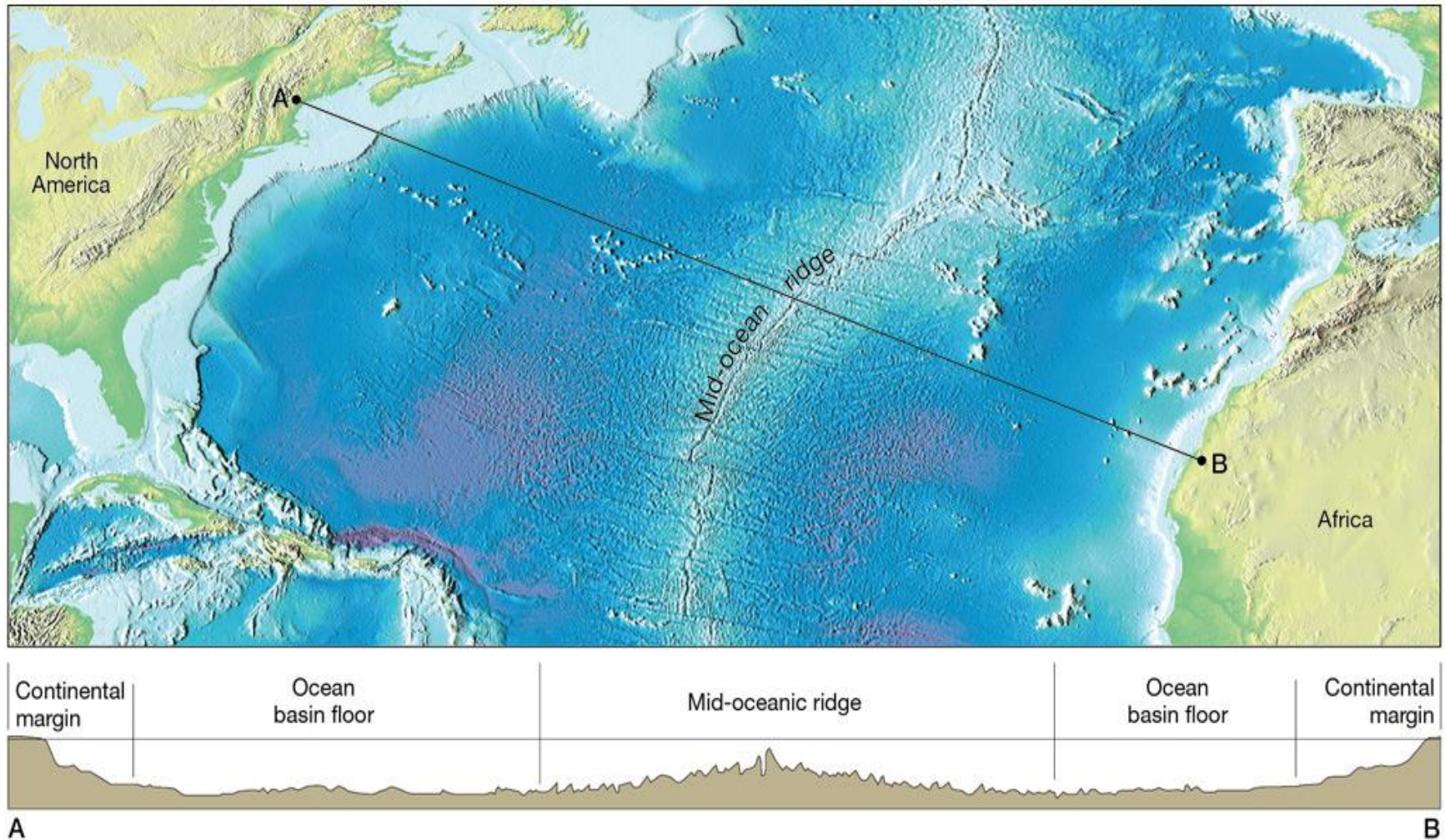
- Originate from polar regions.
- **Cold** and **saline**.
- More *massive* and *move slower* than surface currents.
- Form from warm and saline surface water masses that cool down and sink due to increased density.



**Example:**

**North Atlantic Deep Water**

# North Atlantic Ocean Basin Profile

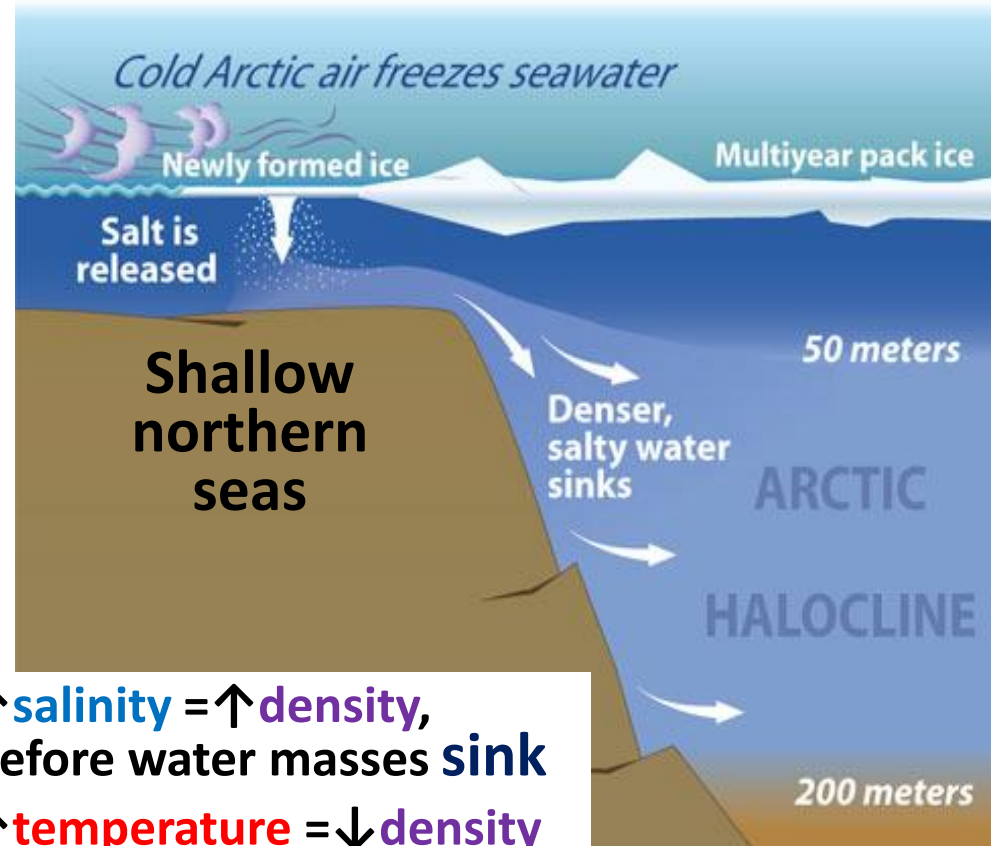
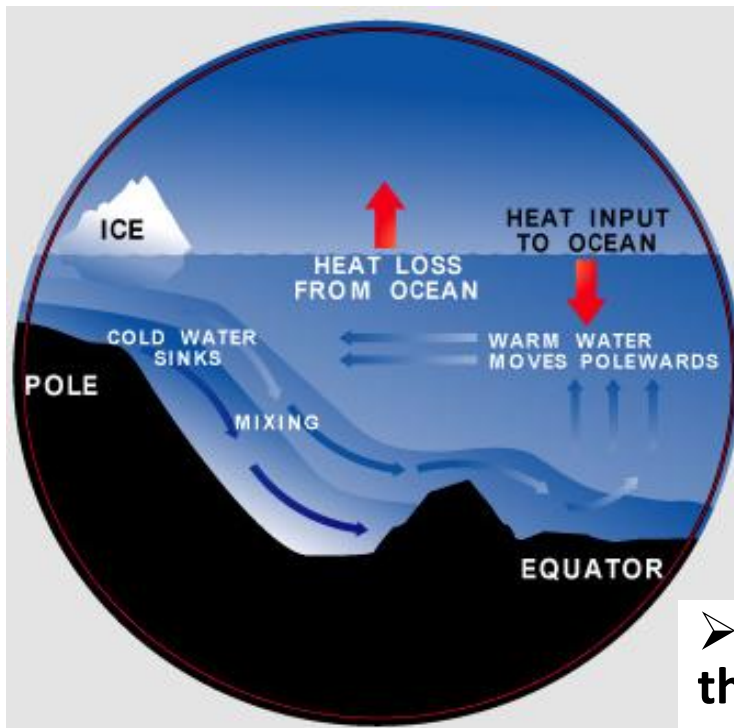


The ocean floor is not flat.  
It has well-pronounced valleys that guide the *deep currents*.



# Vertical Circulation: Thermohaline

Water masses can rise and fall because of **density differences** due to variation of **temperature** and **salinity** with depth.



- $\uparrow$ salinity =  $\uparrow$ density, therefore water masses sink
- $\uparrow$ temperature =  $\downarrow$ density therefore water masses float

# Understanding Water Density

↓ **temperature** = ↑ **density**  
therefore water masses **sink...**

If colder water is more dense than warmer water, and the denser goes under the less dense, **how come ice cubes float?**

Aren't they **colder water** on top of **warmer water**?



**ANSWER:** Water is the only substance that gets denser as it cools down until it is close to freezing...  
...it then becomes less dense!

Note: seawater becomes more dense down to its freezing point at  $-1.8^{\circ}\text{C}$ .